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BERKELEY, CALIFORNIA

SUN-DRYING AND DEHYDRATION OF WALNUTS

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BULLETIN No. 376
MARCH, 1924

UNIVERSITY OF CALIFORNIA PRINTING OFFICE
BERKELEY, CALIFORNIA
1924

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CONTENTS

	PAGE
Methods of Sun-Drying	4
Cost of Sun-Drying	6
The Use of Unheated Drying Houses	7
Early History of Walnut Dehydration	8
Recent Interest in Artificially Drying Walnuts	8
Extent of Dehydration During 1923	10
Advantages of Dehydration	10
Weather Protection	10
Theft Protection	10
Drying Efficiency	10
Labor Efficiency	11
Packing House Efficiency	11
Marketing Efficiency	11
Principles of Dehydration	11
Temperature Effects	13
Critical Temperature for Quality	13
Splitting of Nuts during Curing	15
Relation of Temperature to Drying Time	15
Starting Dehydration at Low Temperature	15
Intermittent Operation of Dehydraters	16
Relation of Humidity to Dehydration	17
Relation of Air Flow to Dehydration	17
Relation of Depth of Walnuts to Air Flow	18
Yields and Storage of Dehydrated Nuts	20
Types of Walnut Dehydraters	21
Natural Draft Dryers	21
Air Blast Dehydraters	21
Bin Dehydraters	22
Tray Dehydraters	24
Mechanical Movement of Nuts During Drying	25
Costs of Dehydration	25

* Paper No. 117, University of California, Graduate School of Tropical Agriculture and Citrus Experiment Station, in coöperation with Division of Viticulture and Fruit Products.

† The authors wish to acknowledge the assistance rendered by the California Walnut Growers' Association in donating Mr. LaRue's services as well as appropriating a fund to further this work.

SUN-DRYING AND DEHYDRATION OF WALNUTS

Walnuts must be dried or "cured" before they can be marketed. This is generally done by exposing them to the sun for several days. The seasonal drying operations usually extend over six or eight weeks, and in cool or moist weather may be very slow and imperfect.

Improper curing may reduce good nuts to "culls" or "near-grades" and depreciate their value 15 to 50 per cent and delay their delivery at the packing house until the association's "second pool," which sells at a discount of 10 or 15 per cent below the "first pool." Non-association growers are not directly affected by the closing of pools but it is the usual practice of commercial buyers to accept late deliveries only at a discount.

Losses of this kind caused by the periodical occurrence of damaging weather in some of the walnut growing districts account for the present interest in walnut dehydration.

As shown in detail on page 10, the advantages of dehydration in promoting fine quality and early marketing because of rapid curing, will be of great value in helping to profitably market the rapidly increasing crops of California walnuts in competition with foreign walnuts.

METHODS OF SUN-DRYING

Walnut drying, commonly referred to as curing, is for the purpose of evaporating the excess moisture in the nuts which, if not removed, would lead to spoilage and a lack of stability in weight. The method as practiced by the pioneers of the industry was described by Joseph Sexton* in 1888:

> The walnuts are picked up and put in sacks and barrels, so as to be easily handled, and hauled to a sunny place to dry, and should be placed on elevated platforms made of narrow boards, with spaces of one-fourth of an inch between each board. The platform should be about 8 feet wide and 40 feet long, or as long as two men can handle a canvas to cover the beds, which should be done every night the dew falls. The nuts should be stirred in these beds once or twice each day, and with favorable weather they will dry sufficiently in three days, and are ready for market.

* Paper read before Ninth Fruit-Growers' Convention, 1888.

Most of the walnuts grown in California are now dried on trays spread in the sunshine or in thoroughly ventilated drying-houses. The practice is as follows: The nuts are spread on shallow slat-bottom trays and exposed to sun and wind. If the air is especially dry and hot, the trays should be spread out in the morning, and when the nuts are well warmed they should be thoroughly stirred and the trays piled up. The slower drying which goes on while the trays are in piles avoids the splitting of poorly sealed nuts and their rejection as culls. Figure 1 shows a yard of trays being piled up after having been thoroughly warmed by the morning sun. The trays should be so piled as to allow ventilation between them.

Fig. 1.—Trays ready to pile up after having been thoroughly warmed by morning sunshine.

The walnuts should not be exposed to showers, fogs, or even heavy dews during the curing process. The alternate wetting and drying of the shells which occur when the nuts are exposed to dew at night and to sunshine during the day, cause many of the nuts to crack at the apex. During the season of 1923, two trays of nuts were cured under identical conditions except that one was covered from sun-down to sun-rise while the other was exposed to the dew and fog. On the uncovered tray 64 per cent of the nuts cracked, on the covered only 4 per cent.

The trays most commonly used are 3 by 6 feet, and 6 inches deep. Extending the sides of the trays 12 inches beyond the ends makes suitable handles. The bottoms are made of laths spaced one-half an

inch apart. The present price for such trays is approximately $2.00 each. Supports are needed for the trays to allow air circulation under and through them while the nuts are drying. Waterproof covers are used for the stacked trays to keep the nuts dry during rain or foggy weather.

COST OF SUN-DRYING

The cost of curing walnuts on trays in the sun was made the subject of a survey during the harvest period of 1923. Twenty-five walnut growers were interviewed in the several walnut growing districts from Irvine to Goleta. The average cost per ton amounted to $5.48, as shown in table 1. This included the overhead charges of depreciation and interest on capital invested in trays and the labor costs in the drying yard from the time the nuts were received from the grove until they were sacked ready for delivery to the packing house. The contract price for performing this service in the districts visited averaged $7.35 a ton. According to figures gathered in 1920 by the Walnut Protective League,* the cost of curing walnuts amounted to approximately $10.00 a ton.

TABLE 1

COST OF SUN-DRYING WALNUTS*

	Tray invesment per ton		Labor per ton		Overhead charge per ton		Total cost per ton
	Number trays required	Total cost	Man Hours	Cost at 40 cents per hour	Interest at 6 per cent	Depreciation at 5 per cent	
Maximum	12.00	$24.00	35.42	$14.17	$1.44	$1.20	$16.81
Minimum	2.66	5.32	0.82	.33	.32	.27	.92
Average	7.78	15.56	9.45	3.77	.93	.78	5.48

* Data from 25 growers producing from 7 to 135 tons, using standard 3 x 6 trays.

The survey summarized in table 1 indicates that the method of sun-drying on trays requires 8 trays per ton of nuts cured during the season. The average production of the groves surveyed was 1200 pounds per acre. With an average production of 1000 pounds per acre a 10-acre grove would require 40 trays to properly cure the crop. The investment in trays alone would approximate $80.00 per 10-acre unit. In addition to this most growers have sheds in which to house the trays when not in use and for the temporary storage of cured nuts.

* American Walnut Industry, by Walnut Protective League, Jan. 1921, p. 23.

The greatest single charge is for labor. According to the growers interviewed, it requires an average of 4 man hours per day to care for 100 trays. Stated on a tonnage basis the average labor cost equalled $3.77 per ton. It is often difficult to obtain the necessary labor as the demand for labor during the walnut harvest season usually exceeds the supply.

Despite certain disadvantages, sun-drying has always been used in the curing of most of the crop. For small orchards it will likely continue to be the most practicable method.

Fig. 2.—Sidwell drying house, outer walls made of slats to give good ventilation.

THE USE OF UNHEATED DRYING HOUSES

In curing large crops it will save labor to use a drying-house such as the Sidwell dryer illustrated in figure 2. The drying houses are usually built with outer walls of slats to give good ventilation. The drying trays or floors are arranged one above another, 8 to 10 in number. The nuts are elevated by conveyors to the top floor on which they are spread in a layer about 6 inches deep. As drying progresses the nuts are dumped mechanically from one floor to the floor below by means of pivoted sections in the floors. The frequency with which the nuts are dumped and consequently the number of days required for drying will depend on the moisture content of the nuts and weather conditions, usually 5 to 7 days in favorable weather.

In hot dry weather the nuts may pass through the drying house in 4 to 5 days. To realize their maximum efficiency such drying houses should be exposed to the full effect of wind and sun without interference from adjacent buildings or trees.

When the nuts on the lowest floor are cured they are dumped into hoppers from which a conveyor transfers them to one end of the drying house for sacking. While the nuts pass along this conveyor, there is an excellent opportunity for an initial culling before delivery to the packing house.

The only advantages of such unheated drying houses are that the nuts are protected from rains, and that the labor cost per ton of nuts cured is less than for tray drying, but this saving is cancelled by the greater overhead charges on the equipment. The saving in labor when the walnut and other farm crop demands are at a peak may make the use of a drying house more practicable than tray drying even though it may be more costly.

The advantages of modern heated dryers for walnuts are obtainable at no greater cost per ton than for unheated drying houses. (See Advantages of Dehydration, p. 10.)

EARLY HISTORY OF WALNUT DEHYDRATION

The curing of walnuts by artificial heat apparently began in the late eighties. Hon. Russel Heath* referred to the methods used in artificially drying walnuts at that time, as follows:

> In handling the nuts, I cure in dry-houses by artificial heat, heating sufficient to evaporate the water and set the oil of the nut. When this is done, the nuts will keep sweet for an indefinite time.

Apparently the early methods of artificially drying walnuts were not entirely practicable, at least the industry was not converted to this method of curing.

RECENT INTEREST IN ARTIFICIALLY DRYING WALNUTS

Aside from the artificial drying of walnuts by a few of the early pioneers in the industry, there have been only a few cases of walnuts being dried by this method until recently. Among the advocates of this method of drying walnuts, the following may be mentioned:

The Corona del Mar Ranch at Goleta has dried walnuts in an old prune dryer for the past 15 to 20 years. The nuts are held in trays

* Essay read by Hon. Russel Heath before the Eleventh State Fruit Growers' Convention, 1889.

over a hot air flue, which is heated by a wood fire in a brick furnace. The temperature maintained is based only on judgment and is regulated by the draft of the furnace. The nuts are received in the dryer *after* passing through the bleaching solution, and are then warmed for a period of 10 to 12 hours.

In 1918 Mr. C. I. Crane of Santa Paula began the practice of drying walnuts with heat from a furnace. The nuts were placed in a wooden slat bottom bin with the heat entering at the bottom. In 1919 the dryer was completely burned. In 1922 a new dryer was installed using steam heating coils underneath a wooden slat bottom bin. Temperatures of from 100° to 118° F. have been maintained, and the nuts dried in from 12 to 48 hours according to their moisture content.

"During the summer of 1920, the San Joaquin Fruit Company* installed a small crude-oil burner and a blower to force the heated air to the drying shed. A bin was built which would hold ten tons of walnuts, or a day's pick, and during bad weather the walnuts were put in this bin and hot air at about 85° to 90° F., was forced in at the bottom for about 18 hours, when the bin was emptied and the process repeated with green nuts. In this manner the outside moisture was driven off, and the curing process in the trays was made shorter."

From this bin dryer the nuts were conducted on a belt to the floors in the drying house.

During the summer of 1920, Mr. F. T. Mahoney built a walnut dryer for Mr. E. C. Kimble of Saticoy. The nuts were poured into a wooden bin with a slanting, slat bottom; hot air was forced into a chamber below this bin, and the draft of hot air passed through the nuts. In 1920 there were 26 tons of nuts dried in this bin dryer.

During the summer of 1921 the dryer on the Kimble ranch was rebuilt, the bin being divided into four compartments. The fan for delivering heated air to the bins was changed from a high speed blower to a slower speed Multivane fan which delivered a greater volume of air per horsepower consumed.

Conveying machinery was added to the Kimble dryer before the harvest season of 1922. Three similar dryers were installed on other ranches the same season. The addition of the conveying machinery for elevating the nuts from a hopper into the bins was a labor-saving device of pronounced value. The interest in this type of bin dryer increased in 1923, when ten additional dryers of this type were constructed in Ventura County.

* From address by C. V. Newman, on Walnut Curing, read before Fourth Annual Walnut Institute, Jan. 1922.

The general interest in curing walnuts by artificial heat was greatly stimulated during the spring of 1922, by an address by Mr. Carl Newman before the Fourth Annual Walnut Institute, held at Santa Ana. Mr. Newman pointed out the fact that methods of curing walnuts had received very little attention or modification since the early development of the walnut industry. As a result of the stimulated interest in this subject, the California Walnut Growers' Association appropriated a fund of $1000 to be used in studying walnut dehydration. This fund has been expended by the field department of the Association, in coöperation with the Agricultural Experiment Station of the University of California. The experiments herein described may be considered a report of the expenditure of this fund, for without this assistance in financing the investigation, the University would have been obliged to greatly curtail its present activity on this problem.

EXTENT OF DEHYDRATION DURING 1923

In 1923 there were 22 walnut dehydraters of various types in operation. The average crop dried per dehydrater was 72.5 tons, making a total amount of 1593 tons. This quantity amounts in general terms to 6.5 per cent of the total crop of walnuts in California. Of the 22 dehydraters in operation in 1923, 13 were operated for the first time that season.

ADVANTAGES OF DEHYDRATION

Careful observation of the operation of all types of walnut dehydraters during the past two seasons has led to the following conclusions regarding the advantages of dehydration as compared with sun-drying in curing walnuts.

1. *Weather Protection.*—Dehydraters may be constantly operated and thus continue the drying process day and night in any kind of weather. Splitting of nuts by dry, hot winds or delayed drying because of fogs or rains are both avoided, with consequent elimination of worry, extra labor, depreciation in the quality of the nuts, and a general financial loss to the grower during unfavorable drying weather.

2. *Theft Protection.*—All harvested nuts are protected from theft by being dried and stored within the dehydrater building until delivered to the packing house.

3. *Drying Efficiency.*—Accurate control of the drying air results in the most uniform, thorough, and rapid drying consistent with the best quality.

4. *Labor Efficiency.*—Dehydraters require considerably less labor per ton of nuts dried. This is an important consideration in the fall of the year when the harvesting of other crops is making demands on the labor supply in competition with walnuts.

5. *Packing House Efficiency.*—Dehydraters afford a steady supply of cured nuts, enabling packing houses to more nearly operate at their maximum efficiency throughout the season.

The effect of some fifteen dehydraters operating in the vicinity of the Saticoy packing house in 1923 on the daily receipts of that house as compared with 1922 is illustrated in figure 3. Even the influence of these few dehydraters did much to equalize the daily delivery of nuts to the packing house with consequent reduction in the cost of packing.

The leveling effect upon the packing load of the Saticoy house during the two seasons may be summarized as follows: The daily packing capacity of the house is 110 tons; the maximum storage capacity is 200 tons. During 1922 the house used extra crews to operate the house 7 Sundays and 16 nights. During 1923 the house operated only 1 Sunday and 6 nights.

6. *Marketing Efficiency.*—Dehydration gains several days over sun-drying; thereby facilitating early marketing which is growing in importance as the tonnage of California walnuts increases. The peak of demand for walnuts occurs before the period of the peak of delivery, therefore, anything which will tend to speed up the wholesale delivery, will stimulate the market. With ordinary harvesting methods plus the use of a dehydrater a grower can feel certain that his entire crop will reach the packing house before the "first pool" closes. The earlier packing house deliveries illustrated in figure 3 were largely the result of dehydration.

PRINCIPLES OF DEHYDRATION

Dehydration may be defined as the evaporation of excess moisture without injury to the products by carefully controlled currents of artificially heated air. This modern method of drying has recently received much study and development in connection with the drying of fruits in California. The fundamental engineering principles underlying the construction and operation of dehydraters for walnuts are very similar to those already published for fruits.* It was necessary, however, to study the behavior of walnuts during dehydration in order to determine what types of equipment and methods of operation resulted in the maximum efficiency in drying compatible with fine quality and economical operation.

* The Construction of Farm Dehydraters in California, by A. W. Christie and G. B. Ridley, Journal of the American Society of Heating and Ventilating Engineers, Vol. 29, No. 9. December, 1923.

The time required to evaporate the excess moisture in walnuts is dependent on the following factors:

1. The maximum temperature at which walnuts can be safely dehydrated.
2. The per cent of excess moisture in the nuts when harvested.
3. The volume of heated air reaching the nuts.
4. The relative humidity of the air.

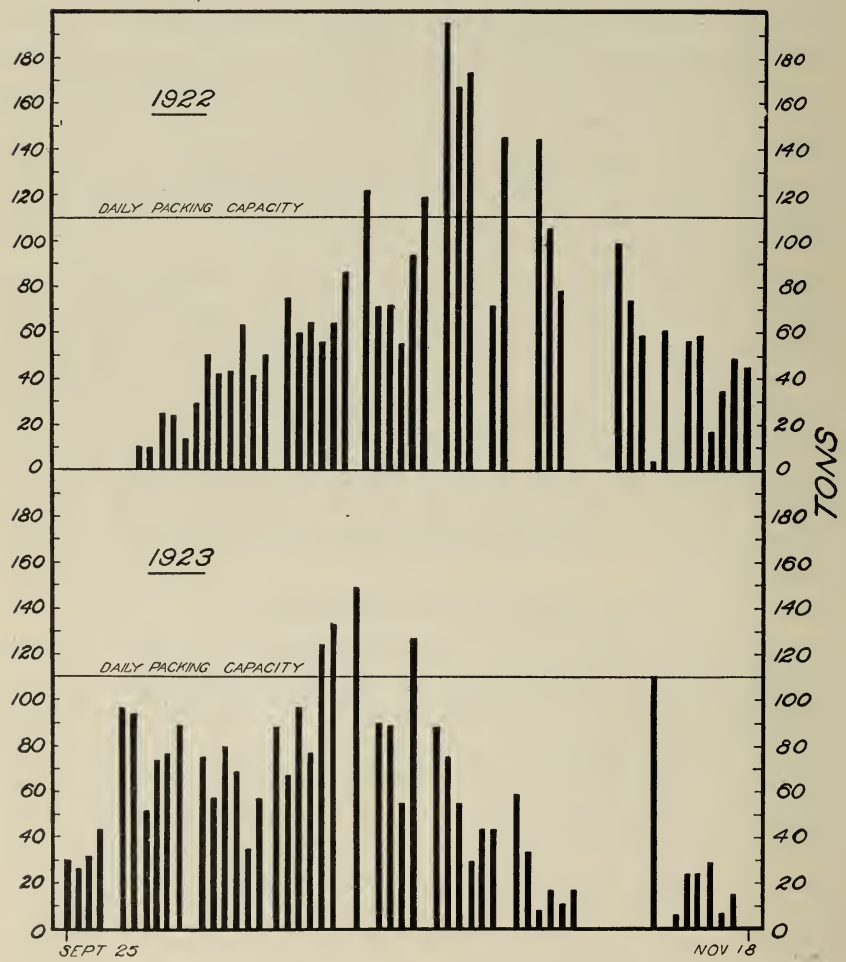

Fig. 3.—Comparative daily delivery of nuts to Saticoy packing house.

The following paragraphs set forth briefly the results of numerous tests on the dehydration of walnuts and the bearing of this information on the construction and operation of walnut dehydraters:

TEMPERATURE EFFECTS

The evaporation of water requires the expenditure of a definite amount of heat (approximately 1000 British Thermal Units per pound of water evaporated). In the case of walnut dehydraters this heat is most conveniently and economically generated in oil-burning furnaces. It is obvious that the higher the temperature of the air conveying this heat from the furnace to the nuts, the more rapid will be the evaporation of moisture from the nuts.

TABLE 2

RELATION OF TEMPERATURE OF DEHYDRATION TO QUALITY OF WALNUTS

Per cent water when harvested	Drying temperature	Percentage showing oil on kernel	Eating quality	
			After drying	After 4 months*
32	100°F.	76%	normal	normal
37	100°F.	28%	normal	normal
46	105°F.	15%	normal	normal
38	110°F.	30%	normal	injured (stale and bitter)
30	110°F.	44%		normal
18	110°F.	20%	normal	normal.
22	110°F.	56%	normal	slightly injured
17	115°F.	34%		slightly injured
36	120°F.	60%	normal	injured (flat, slightly rancid)
29	130°F.	80%	pleasant but cooked flavor	rancid (not edible)
35	140°F.	100%	unpleasant oily flavor	rancid (not edible)

* Held in common storage.

Critical Temperature for Quality.—Most food products have a "critical" temperature beyond which they cannot be heated without danger of injury to their quality. The results of a series of carefully controlled temperature tests are shown in table 2, from which it can be seen that the "critical" temperature for walnut dehydration is in the neighborhood of 110° F. It was also evident that the higher the per cent of moisture in the nuts when harvested, the lower the "critical" temperature. The dehydrated nuts were always compared with sun-dried nuts which came from the same respective original lots. It may

be concluded, therefore, that in no case should walnut dehydraters be operated above 110° F., and in the case of very moist nuts from early harvesting, it is imperative not to exceed 105° F. Walnuts dehydrated in 1922 were still in first-class marketable condition at the end of 18 months.

TABLE 3

COMPARATIVE DRYING DATA ON SUN-DRYING AND DEHYDRATION OF WALNUTS

(Orange County, 1923)

Date of harvest	Method of drying	Per cent water in nuts before curing	Per cent of weight lost in drying	Per cent of water in cured nuts	Per cent of nuts unsealed after curing	Drying time, hours	Drying temperature
Sept. 15	*Sundried*	*46.25*	*32.32*	*8.87*	*2.25*	*224*	*65°*
Sept. 15	Dehydrated	46.25	36.19	5.11	0.00	46	105°
Sept. 17	*Sundried*	*37.70*	*31.56*	*7.25*	*4.00*	*240*	*58°*
Sept. 17	Dehydrated	37.70	33.57	5.48	0.00	36	110°
Sept. 19	*Sundried.....*	*36.00*	*25.78*	*7.33*	*8.00*	*200*	*64°*
Sept. 19	Dehydrated	36.00	30.57	5.66	0.15	24	120°
Sept. 20	*Sundried*	*28.76*	*27.14*	*6.94*	*5.50*	*195*	*64°*
Sept. 20	Dehydrated	28.76	27.72	7.45	0.27	18	130°
Sept. 22	*Sundried*	*35.11*	*33.21*	*6.79*	*4.00*	*170*	*65°*
Sept. 22	Dehydrated	35.11	27.64	6.91	0.04	14	140°
Sept. 24	*Sundried*	*36.60*	*30.30*	*8.04*	*2.00*	*198*	*66°*
Sept. 24	Dehydrated	36.60	30.05	9.29	0.08	30	100°
Sept. 25	*Sundried*	*33.18*	*29.85*	*8.02*	*2.00*	*222*	*67°*
Sept. 25	Dehydrated	33.18	27.90	8.49	0.07	42	90°
Sept. 28	*Sundried*	*31.55*	*27.14*	*3.67*	*9.00*	*198*	*72°*
Sept. 28	Dehydrated	31.55	25.30	7.00	0.08	32	100°
Sept. 30	*Sundried*	*29.82*	*20.53*	*3.94*	*6.50*	*122*	*67°*
Sept. 30	Dehydrated	29.82	20.59	4.44	0.00	46*	110°
Oct. 2	*Sundried*	*18.45*	*17.50*	*3.98*	*6.00*	*184*	*67°*
Oct. 2	Dehydrated	18.45	14.24	4.74	0.00	32†	110°
Oct. 8	*Sundried*	*21.64*	*16.03*	*3.77*	*11.00*	*120*	*68°*
Oct. 8	Dehydrated	21.64	16.96	5.52	0.28	28	110°
Oct. 10	*Sundried*	*16.72*	*9.69*	*4.04*	*13.00*	*96*	*71°*
Oct. 10	Dehydrated	16.72	14.85	2.47	0.86	20	115°
Averages	*Sundried*	*30.89*	*25.09*	*6.26*	*6.10*	*181*	*66°*
	Dehydrated	30.89	25.46	6.09	0.15	31	112°

* Includes 10-hour shut-down after 12 hours of drying. *Fan Off.*
† Includes 10-hour shut-down after 12 hours of drying. *Fan On.*

Because of the danger from higher temperatures, it is important that all walnut dehydraters be adequately equipped with accurate thermometers. The temperature of dehydraters heated by oil, gas, steam or electricity can be automatically controlled by thermostats which eliminate the danger of over-heating as well as the necessity for the frequent temperature observations in manually operated plants.

Splitting of Nuts during Curing.—Another valuable observation associated with quality is noted in the sixth column of table 3. The average per cent of nuts split during dehydration was only 0.15 per cent as compared with 6.1 per cent during sun-drying of similar lots. In no case did the per cent of split dehydrated nuts reach 1 per cent, while in sun-drying it rose as high as 13 per cent. This is a distinct advantage in favor of dehydration.

Relation of Temperature to Drying Time.—The comparative drying times of sun-drying and of dehydrating nuts can be seen in the seventh column of table 3. Sun-drying required from 4 to 10 days, averaging 7½ days, while dehydration required from 14 to 46 hours, averaging 31 hours. The greater speed of dehydration (about six times as fast) is due, first, to the higher temperature obtainable, and, second, to the maintenance of this temperature throughout the drying period. Most of the daily evaporation of water in sun-drying occurs during a few hours in the middle of the day, while dehydration is continuous until completed. Cool, moist nights alternating with warm, dry days not only delay drying but cause the splitting of nuts from alternate expansion and contraction.

It is difficult to give an average drying time for walnuts at different temperatures because, although the conditions of dehydration be under exact control, the initial percentages of moisture in different lots of nuts vary greatly. However, the following averages obtained from all experiments made in 1922 and 1923 conclusively show the advantage of operating a walnut dehydrater at the maximum safe temperature.

Temperature	Hours required to evaporate 1 per cent of moisture
90° F.	2.56
100° F.	2.17
110° F.	1.51

The use of temperatures below the maximum safe temperature merely results in lengthening the time of drying with consequent decrease in the capacity of the dehydrater and increase in the cost of drying.

Starting Dehydration at Low Temperatures.—No valid objection was found to beginning the dehydration of walnuts at the maximum temperature to be used. Slow "warming up" of the nuts merely increased the time and cost of drying.

INTERMITTENT OPERATION OF DEHYDRATERS

A number of dehydrater operators practice intermittent operation, the furnace and fan being shut off for about 10 hours during every night. It was thought that the nuts would continue drying during this period. This practice was made the object of an exact study, the results of which are shown in figure 4. It is evident that as soon as the flow of heated air ceases, there is little or no further drying of the nuts until the dehydrater is started again. In certain instances there may be other factors, such as labor supply, which justify intermittent operation, but from a standpoint of drying efficiency it merely reduces the capacity and increases the cost per ton of operating the plant.

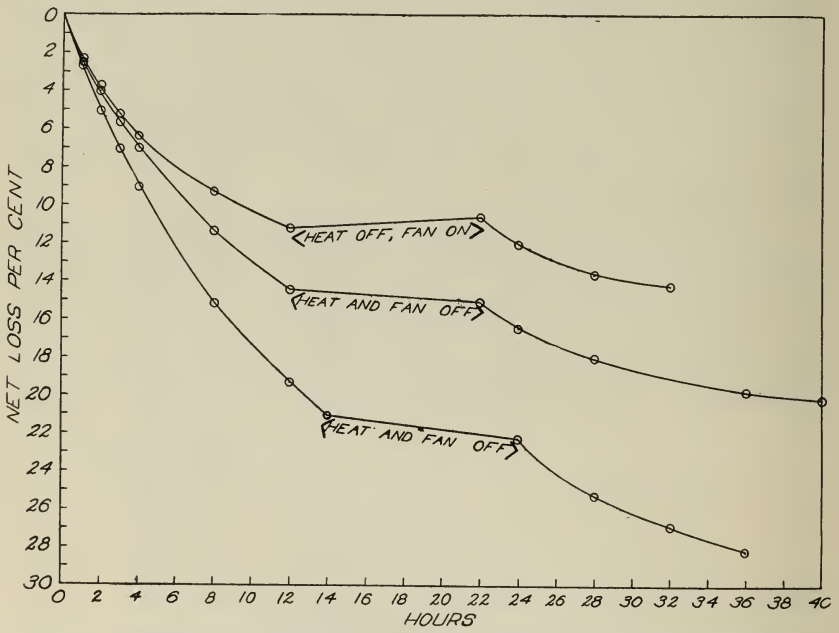

Fig. 4.—Effect of intermittent operation on dehydrating time of walnuts. Drying temperature, 110° F.

Some operators thought that during the nightly shut-down period a considerable amount of moisture equalization occurred between the already dried and the still moist nuts which might be mixed together in the bins. For the purpose of ascertaining the extent of such equalization, a lot of thoroughly cured nuts were individually marked, mixed and sacked with an equal weight of uncured nuts. At periodic intervals, the respective lots were separated and weighed. The results showed that the absorption of moisture by the cured nuts from the

uncured nuts was negligible and therefore of no value in obtaining even drying.

In other words, the drying of each individual nut proceeds independently until its moisture content reaches an equilibrium with the moisture content of the surrounding air.

RELATION OF HUMIDITY TO DEHYDRATION

The lower the relative humidity of air the greater its moisture absorbing power. The relative humidity of air is halved and consequently its moisture holding capacity doubled for every 27° F. rise in temperature. Hence, outside air saturated with moisture at 56° F. would have its moisture holding capacity quadrupled when heated to 110° F. in a dehydrater. This explains why dehydraters continue drying irrespective of external atmospheric changes.

No specific experiments were made on the effect of air of different degrees of humidity on the drying time of walnuts, but it was observed incidentally that a material increase in the relative humidity of the air resulted in a slightly retarded rate of drying of the nuts. However, there is no danger from this source since the volume of air required to convey to the nuts the necessary heat for moisture evaporation is several times that required to absorb this evaporated moisture. Hence, the retardation of drying by a wholly or relatively heavily saturated air is rarely encountered in walnut dryers, except in the case of a natural draft dryer operated with closed vents.

RELATION OF AIR FLOW TO DEHYDRATION

Air currents serve two essential functions in any dehydrater: first, to convey the heat required for moisture evaporation from the source of heat to the material to be dried, and second, to absorb and carry away the water vapor produced. The amount of evaporation in a given time is dependent on the amount of heat reaching the nuts. The amount of heat is in turn controlled by:

a. The temperature of the air.

b. The volume of the air.

It has already been shown that the temperature of the air must not exceed 110° F. Consequently, any increase in the speed of drying must be brought about by increasing the volume of air and therefore the amount of heat reaching the nuts in a given time.

Air flow in dehydraters is secured in one of two ways:

a. Natural draft produced by the expansion of heated air.

b. Forced draft produced by power-driven fans.

The latter method is used in most modern dehydraters because natural drafts are usually inadequate in volume and *difficult* to *properly direct and distribute.* The effect of increased air flow on reducing the drying time of walnuts can be seen in table 4. In walnut tray dehydraters, velocities in excess of 500 feet per minute over the trays do not warrant the increased expenditure for such air flow. On the other hand, air velocities much below 500 feet per minute greatly increase the time and cost of drying.

TABLE 4

RELATION OF AIR VELOCITY TO DRYING TIME OF WALNUTS

Method of drying	Average temperature F°	Air velocity (ft. per min.)	Drying time (hours)	Per cent water lost
Sun-dried	72	.....	122	27
Dehydrater	100	250	40	24
Dehydrater	100	500	32	25
Dehydrater	100	1000	28	21
Dehydrater	100	Nat. Draft	33	9
Dehydrater	100	500	16	9

Most walnut dryers built so far are imperfect because of inadequate and uneven air flow. Only by the use of fans of sufficient power can the most rapid and uniform drying be obtained. Dependence on natural draft or the use of fans of insufficient capacity is false economy.

RELATION OF DEPTH OF WALNUTS TO AIR FLOW

Since the bin type of dryer seems to be the most generally satisfactory for walnuts, an experiment was made to determine the effect of various depths of walnuts on the flow of air through them. From the graphic presentation of the results in figure 5, it can be seen that the first 6 to 12 inches of walnuts practically determines the volume of air which a given fan can force through the nuts. Increasing the depth of nuts does not alter the free area for air passage but merely decreases the air flow slowly in proportion to the increased frictional resistance to its passage. In bin dryers the heated air should be delivered from the fan to the bottoms or sides of the bins by the largest, shortest, and straightest flues which can be used. The air should enter at a central point from which it can be equally distributed to all parts of the bin. This can be accomplished by causing the air to enter at the center of the bottom or side of the bin from where it can be evenly distributed over the entire bin by proper arrangement of baffles.

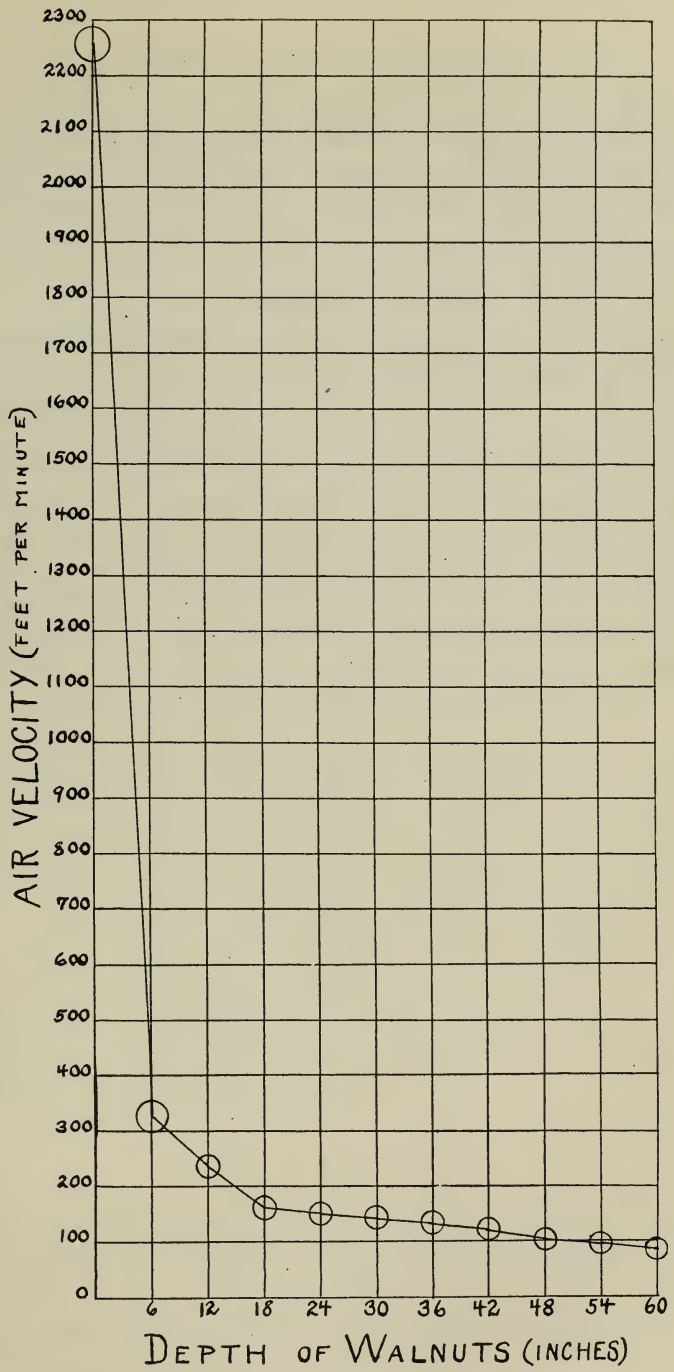

Fig. 5.—Effect of depth of walnuts on air velocity.

YIELDS AND STORAGE OF DEHYDRATED WALNUTS

Since the curing of walnuts consists of the evaporation of excess moisture, there should be no difference in yields by sun-drying or dehydration, provided the nuts are reduced to the same degree of dryness in both cases. From table 3 it can be seen that, although there were occasional differences in the losses in weight by the two methods of drying, these differences were not consistently in favor of either method and that the seasonal averages were almost identical.

Figure 6 shows the average changes in weight during storage for the dehydrated and for the sun-dried nuts referred to in table 3. The unusually dry winter of 1923–24 in southern California caused both lots to lose over 2 per cent of their weight in storage, but during a period of relatively high humidity caused by spring rains the nuts regained their original weight, showing that they had been dried to the proper degree for normal winter storage. The dehydrated nuts had evidently been cured a little more thoroughly, as shown by the average moisture contents given at the bottom of column 5, table 3. This was confirmed by their slightly smaller change in weight during storage.

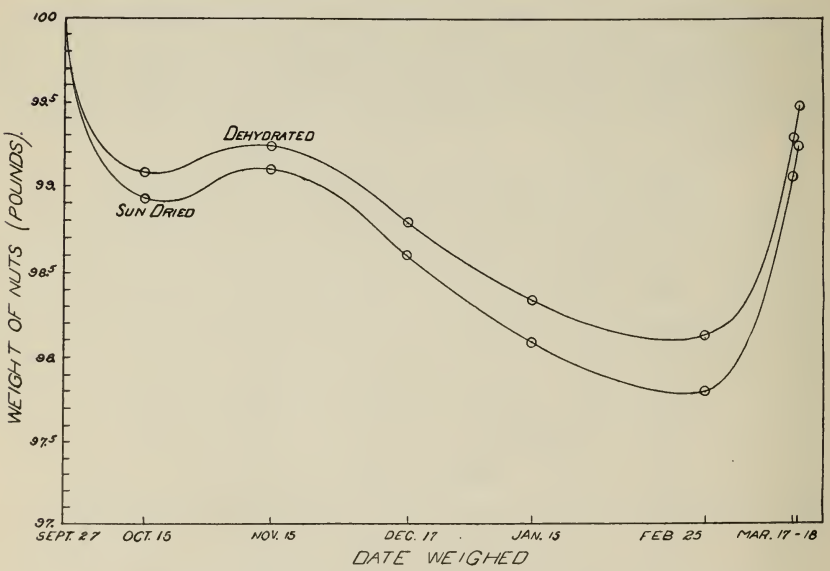

Fig. 6.—Changes in weights of walnuts during storage (Riverside, 1923–24).

TYPES OF WALNUT DEHYDRATERS

It is not the purpose of this publication to present complete plans and specifications for dehydrater construction. However, a brief description of the more common types of walnut dehydraters, with their relative advantages and disadvantages, should be of interest to prospective purchasers.

NATURAL DRAFT DRYERS

Probably the simplest form of dryer consists in closing drying houses, such as the Sidwell Dryer described on page 7, with solid walls and placing one or more small furnaces on the ground under the bottom floor. This permits such a drying house to continue drying in cold or damp weather, because the outer air drawn in through openings near the ground is heated by passing over the furnaces, rises through the floors of nuts and eventually escapes through a ventilator in the roof, carrying with it some moisture evaporated from the nuts.

In another type of natural draft dryer a series of vertical screen walls, some 6 inches apart, is substituted for the screen floors. The space between each alternate pair of walls is filled from above with nuts, the alternate open spaces being reserved for the upward passage of heated air.

These and similar modifications of natural draft dryers have two distinct advantages over sun-drying in that they reduce labor in handling the nuts and continue drying in all kinds of weather. From the standpoint of efficient dehydration, however, such dryers are imperfect. They occupy more space than bin type dehydraters of equal capacity. The air flow is only sufficient for relatively slow drying. Since natural air currents follow paths of least resistance, it is very difficult to distribute the air and heat so as to insure even drying, especially when the dryer is only partly filled. The temperature in natural draft dryers is subject to wide fluctuations which cannot be regulated without close watching.

AIR BLAST DEHYDRATERS

The use of fans in dehydraters to furnish a strong, constant flow of heated air, the temperature and distribution of which are under rather exact control, has now become almost universal. Although there are numerous modifications in this class, the tunnel type using trays and the bin type are of greatest interest because both have been successfully used on walnuts for several years.

Bin Dehydraters are a class developed for the drying of walnuts only. They consist of three essential parts: one or more bins for holding the nuts, a furnace or other device for generating heat, and a fan for conveying heated air from the furnace to the bins.

One type consists of bins about 10 feet square, the bottoms of which are made of slats or screen and in the form of inverted pyramids. In another type (illustrated in figs. 7, 8, and 9) rectangular bins, usually 6 feet by 16 feet, are built on about a 30 degree slope, with a false, slatted floor forming an air chamber some 6 inches deep beneath the nuts. The capacity of a bin dryer may be determined by multiplying the cubical contents by 35 pounds of cured nuts per cubic foot.

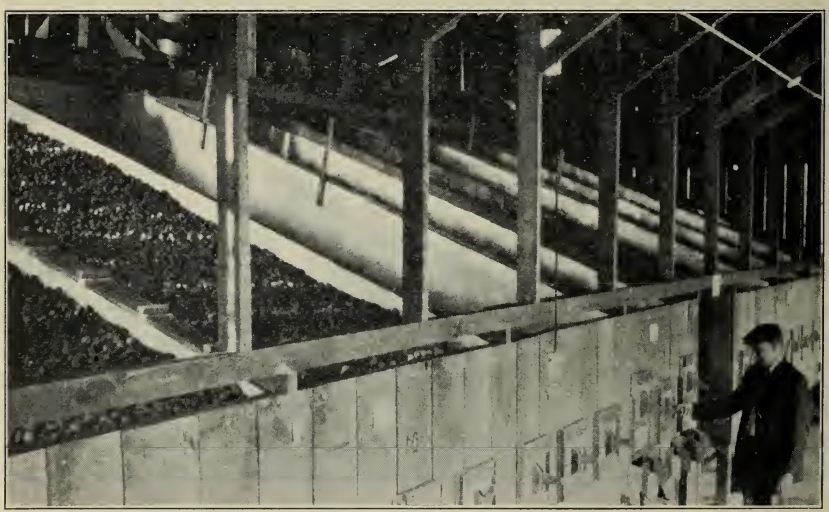

Fig. 7.—Full and empty bins and sacking device. Mahoney bin dryer.

A blast of heated air is introduced into the bottom of each bin through flues leading from a fan, one fan and furnace usually supplying a battery of four bins. The bins are filled with nuts from above to a depth of 2 to 3 feet by means of a simple elevator and conveyor, giving a maximum capacity per bin of 2½ tons of nuts.

In both of these types the air heating equipment is located close by. This usually consists of either a standard oil burning furnace, such as is used for heating buildings, or a simpler heating chamber utilizing direct heat from electricity or gas. Outside air is drawn through the heating chamber by a fan and delivered through flues to the bottoms of the several bins. It then rises through the mass of nuts and eventually escapes into the outer air, carrying with it the moisture which the heat has caused to evaporate from the nuts.

The best type of fan for this purpose is that known as the Multivane, which delivers the maximum volume of air for the horsepower expended and operates successfully against considerable back pressure caused by resistance to the flow of the air through the bins of nuts.

The time required in such dryers varies according to the moisture content of the nuts and the operating temperature. Constant operation at 100° F. to 110° F. will complete drying in 24 to 48 hours. Proper

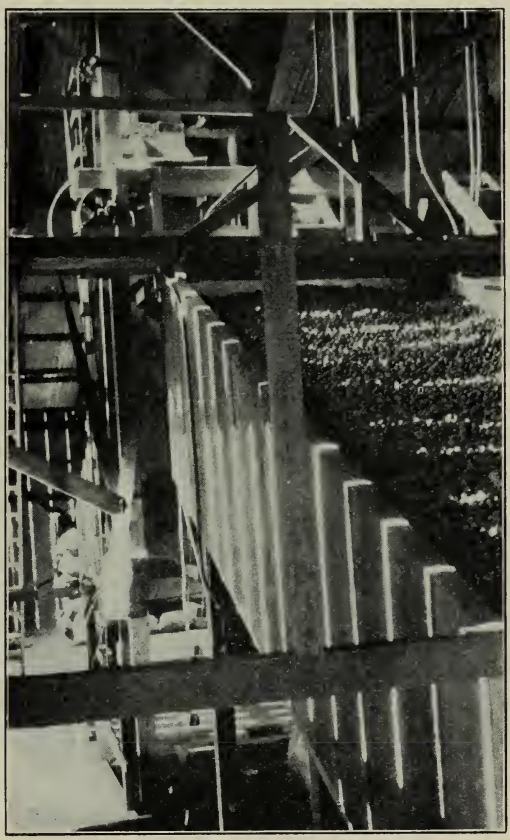

Fig. 8.—Elevator and conveyor for filling a Mahoney bin dryer.

construction and arrangement of the bins and air ducts will result in uniform distribution of heated air throughout the bin and consequently in even drying.

When the nuts are dry they are either drawn by gravity directly into sacks from the bottom of each bin or discharged into a common conveyor which carries the nuts to a central point for sacking.

These bin dryers are generally considered the most satisfactory type for walnuts yet developed. They provide the maximum daily capacity for the investment involved and the space occupied. They are susceptible of exact yet simple regulation of the temperature and distribution of air and consequently permit the most rapid and thorough drying consistent with quality. They are most economical of labor, one man being easily able to load, dry, unload and sack 5 tons of nuts daily.

The dryers of this type so far constructed have not realized their greatest possible efficiency because of the use of fans and motors of inadequate size. The lower the air flow the slower and more uneven the drying. It is also probable that recirculation of the warm exhaust air, as practiced in all modern fruit dehydraters, would result in greater fuel efficiency.

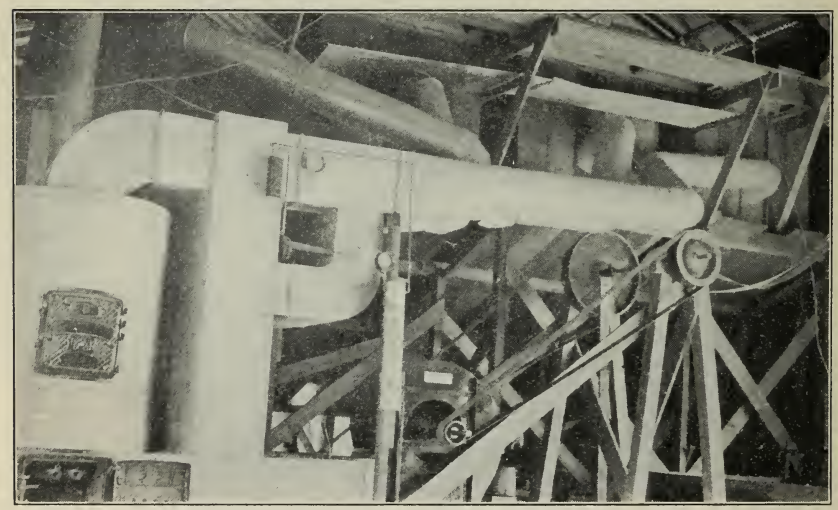

Fig. 9.—Furnace, fan and flues for distributing heated air to a four-bin Mahoney dryer.

Tray Dehydraters.—Tray dehydraters for fruits are now in extensive use in California as well as in the Pacific Northwest. The soft texture of all fruits except apples necessitates the use of trays in drying. There are many types of tray dehydraters in use, but the type considered most generally satisfactory is known as the Tunnel dehydrater, consisting of a long chamber 6 or more feet wide by 7 feet high. The trays are entered at the cooler end on slides or cars and moved progressively toward the hotter end from which they are removed when

the contents are dried. Some of the small dehydraters depend on a natural draft of heated air, but most of the modern installations include a furnace and fan located in an auxiliary chamber alongside, above or below the drying tunnel in such a way that a powerful, controlled stream of heated air is blown between the trays of material in the tunnel and either discharged or recirculated from the exhaust end of the tunnel.

This type of dehydrater has been successfully used on walnuts in both Oregon and California. It gives the most rapid and uniform drying of all types and is most economical of fuel. However, the first cost is greater for its capacity than that of bin dryers and the extra labor required in loading and unloading the trays makes the cost of drying walnuts considerably greater. The capacity of a tray dehydrater may be determined by multiplying the total square feet of tray surface by 2 pounds of cured nuts per square foot for trays filled one nut deep. Except for growers who desire to dry other fruits as well, tray dehydraters are not advisable. Since the economic dehydration of all fruits necessitates the use of higher temperatures than are permissible for walnuts, fruits and walnuts cannot be dried simultaneously.

MECHANICAL MOVEMENT OF NUTS DURING DRYING

Dehydraters involving mechanical devices for the constant or intermittent movement of nuts during drying are unnecessarily complicated and expensive to build and operate. It is sounder in principle to bring the warm air to the nuts than to attempt to bring the nuts to the air.

COSTS OF DEHYDRATION

The advantages of walnut dehydration listed on page 10 would be of little interest to growers if such advantages could only be obtained at greatly increased costs. The use of walnut dehydraters has not yet become sufficiently general to permit of the gathering of extensive data on the cost of dehydration. However, the costs of operation presented in table 5 are considered typical of present practice.

It can be seen that although the fixed charges per ton for the bin dryer are greater than for sun-drying, because of the greater investment, the operating costs are sufficiently lower, because of labor saving, to make the total cost about the same. The moderate cost of power and fuel is easily counterbalanced by the saving in labor. It is reason-

able to expect that, as the construction and operation of walnut dehydraters is perfected, their cost of operation will decrease to an amount less than that of sun-drying, as already realized in the case of modern prune dehydraters.

TABLE 5

COMPARATIVE COSTS PER TON OF SUN-DRYING AND DEHYDRATING WALNUTS IN 1923

	Sun drying	Bin dryer	Tray Dryer
Labor	$3.77	$1.61	$3.13*
Fuel	.....	1.04	2.12†
Power	.....	.23	.92
Total Operating Cost	$3.77	$2.88	$6.17
Fixed Charges‡	1.71	2.75	2.00
Total all costs	$5.48	$5.63	$8.17

* Includes hulling and washing.

† Electric heat; equivalent to 14 cents if oil used.

‡ Interest and depreciation at 11 per cent.

Walnut dehydraters are still in a state of development, but they have already sufficiently established their desirability to warrant careful consideration by all walnut growers. Their advantages are obtainable at no greater final cost than that of sun-drying. Their only disadvantage is the greater initial cost of the equipment.

The cost of a completely equipped and housed walnut dehydrater will vary considerably with the type, size, materials of construction, etc., but for an efficient dehydrater of medium size will approximate $500 to $600 per ton daily capacity.

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